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EARLY ADVANCED DEVELOPMENT OF ARMING SAFETY DEVICE FOR 5-INCH G--ETC(U)
FEB 78 J L BEARD MIPR-N60921-77-MP-RD004
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The Harry Diamond Laboratories performed early advanced development of the EX18 Mod 0 Arming Safety Device (ASD) for the Navy's 5-in. guided projectile. The design of the ASD is functionally similar to the design of the safety and arming mechanism for the Navy's 8-in. guided projectile. The ASD responds to launch acceleration and muzzle exit signatures. The early advanced development was performed in two phases. In phase I, the ASD was designed, and

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three prototypes were fabricated and tested in the laboratory. In phase II, the design was refined, 35 ASD's and a larger number of explosive mockups were fabricated, and a series of qualification tests was performed. The qualification tests ranged from laboratory tests to drop tests and gun firings. The design was further refined during and following the qualification tests. The feasibility of the design was demonstrated and areas of the design requiring additional work were identified.

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APPENDICES



FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)



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## 1. SCOPE

This report describes the early advanced development (September 1974 to September 1976) of the EX18 MOD 0 Arming Safety Device (ASD) for the 5-in. guided projectile (5-in.), shown in figure 1. The work was performed by the Harry Diamond Laboratories for the Naval Surface Weapons Center, Dahlgren Laboratory (NSWC/DL), Dahlgren, VA, the developer of the projectile. The design of the ASD is functionally similar to the design of the safety and arming mechanism (S&A) for the 8-in. Guided Projectile (8-in.), shown in figure 2.

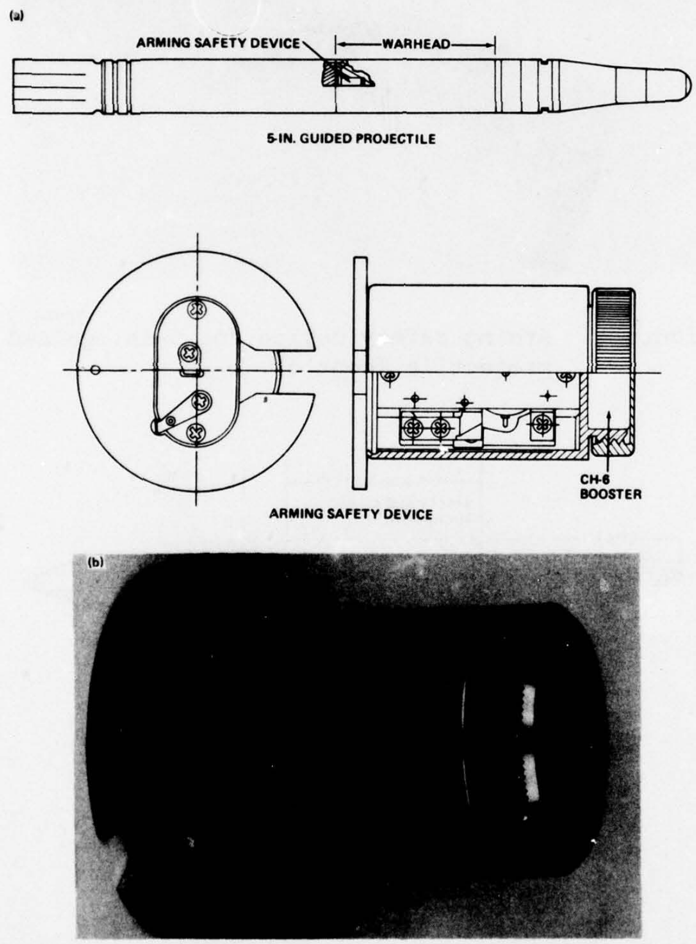


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Figure 1. Arming safety device for 5-in. guided projectile.

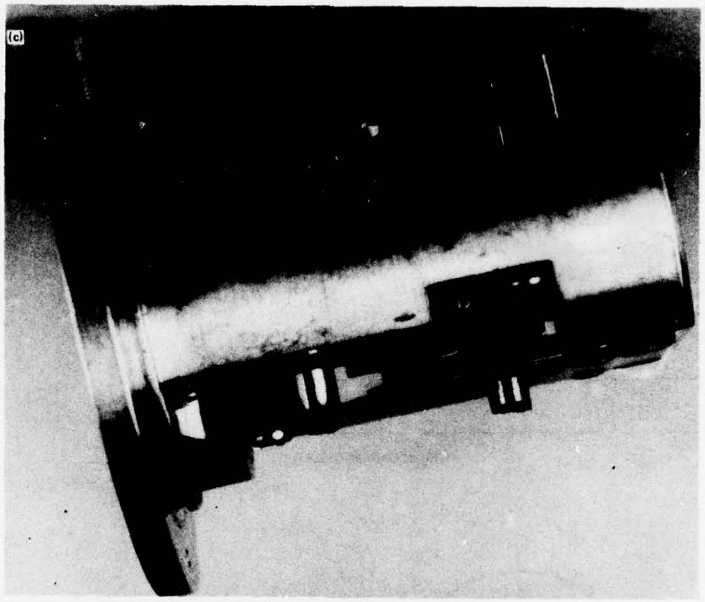


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Figure 1. Arming safety device for 5-in. guided projectile (cont'd).

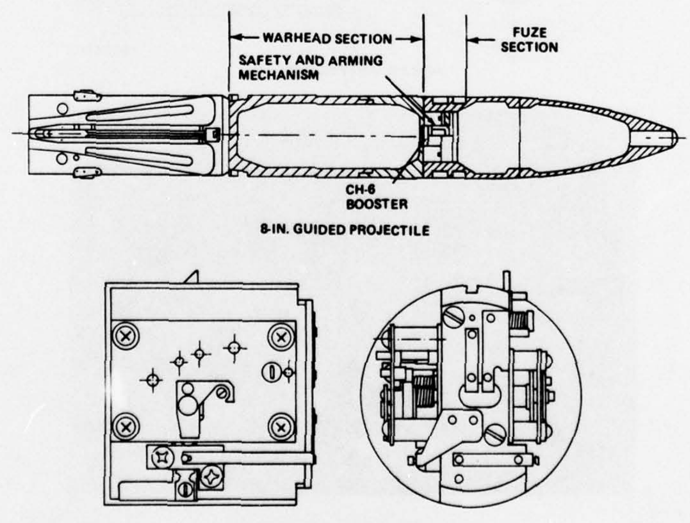


Figure 2. Safety and arming mechanism for 8-in. guided projectile.

The early advanced development was performed in two phases. Phase I consisted of design, fabrication, and laboratory tests of three ASD prototypes. Phase II consisted of design refinement, fabrication of 35 ASD's and a greater number of explosive mockups, and a series of preliminary qualification tests. Additional design refinements were made during and following the qualification tests.

## 2. BACKGROUND AND REQUIREMENTS

In September 1974, HDL began developing an ASD for the Navy 5-in. guided projectile under the sponsorship of NSWC/DL. The ASD was designed to meet the following requirements and weapon characteristics:

a. Safety requirements

(1) Maximum safety failure rate: 1 in 2.5 million

(2) Design safety requirements[1] of MIL-STD-1316

(a) Out-of-line safety

(b) Dual environment safety: two independent locks on the out-of-line element of the explosive train, each operated by a separate environment unique to launch

(c) Alignment of the explosive train without the use of stored energy (actually an objective of MIL-STD-1316, treated as a requirement by NSWC/DL)

(d) Antiarmed assembly feature: a feature to prevent installation of an armed ASD into its enclosing can

(3) Desired safe separation time: 0.5 to 1.0 s

b. Weapon characteristics

(1) Range of peak launch accelerations: 1000 to 8000 g

(2) Warhead: shaped charge (must be initiated at aft end--therefore, ASD must fire forward)

(3) Envelope available for ASD: 1-1/2 in. (3.81 cm) in diameter, including an enclosing can, and 2 in. (5.08 cm) in length, including three electrical contacts at the bottom and a lead charge at the top, but not including the mounting flange and booster pellet

[1]*Fuze, Design Safety, Criteria for, Department of Defense MIL-STD-1316A (17 September 1970).*

The design of the ASD for the 5-in. is based on the design of the S&A for the 8-in. However, the 5-in. ASD and the 8-in. S&A differ in the following ways due to different weapon characteristics:

a. Direction of firing: the 5-in. ASD fires forward, whereas the 8-in. S&A fires to the rear.

b. Safe separation time: for the 5-in. ASD, the time is 0.5 to 1.0 s, whereas for the 8-in. S&A, the time is 1.5 to 3.0 s.

c. Range of peak launch accelerations to which it must respond: for the 5-in. ASD, the range is 1000 to 8000 g, whereas for the 8-in. S&A, the range is 2500 to 10,000 g. The 1000-g minimum peak launch acceleration for the 5-in. ASD arose from the possibility of launching the 5-in. from the 155-mm howitzer.

d. Size and shape: the envelope available for the 5-in. ASD and its enclosing can is 1-1/2 in. (3.81 cm) in diameter and 2 in. (5.08 cm) in length, whereas the envelope available for the bare 8-in. S&A is 1-3/4 in. (4.44 cm) in diameter and 1-3/4 in. (4.44 cm) in length.

## 3. FUNCTIONAL DESCRIPTION

The 5-in. ASD consists of the following (fig. 3):

a. A housing

b. A rotor containing an electric detonator, which is the out-of-line element

c. An antiarmed assembly lever

d. An untuned escapement to slow the motion of the rotor to yield the desired arming delay

e. A sequential leaf, acceleration sensing mechanism that, upon setback, cocks a spring to provide the energy to drive the rotor into line and removes the first lock from the rotor

f. The locking and actuating portion of a muzzle exit sensing system that removes the second rotor lock (Muzzle exit recognition is accomplished by two induction sensors and a logic circuit elsewhere in the projectile.)

g. A contact board

h. A can containing a lead charge and a booster

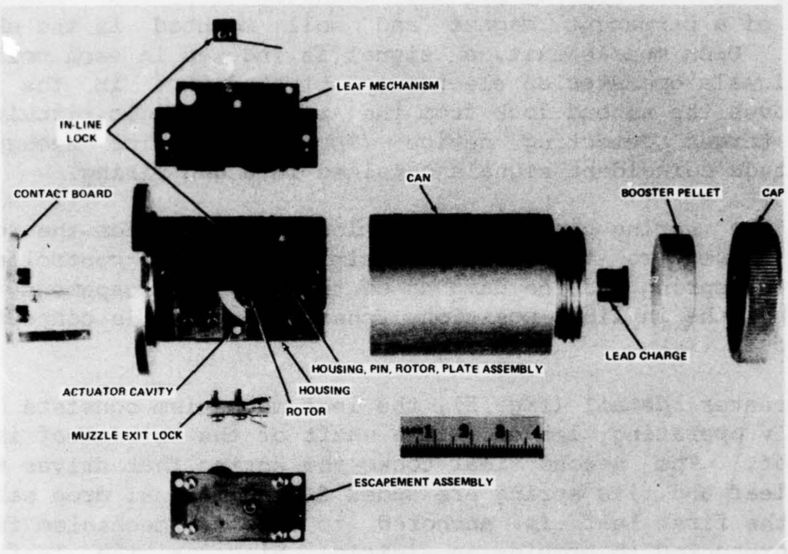


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Figure 3. Major subassemblies of arming safety device.

The sequence of operations is as follows (fig. 4): Upon setback, the leaf mechanism cocks a spring to provide the energy to drive the rotor into line and removes one lock from the rotor. The leaf mechanism can distinquish between a gun firing and an accidental drop and does not release the rotor in drops from up to 40 ft (12.19 m).

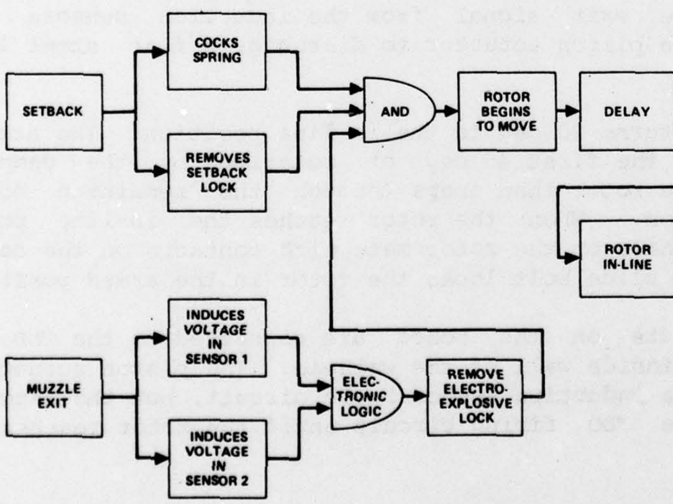



Figure 4. Sequence of functions.

Muzzle exit is sensed by two magnetic induction sensors, each consisting of a permanent magnet and coil mounted in the skin of the projectile. Upon muzzle exit, a signal is induced in each coil. Energy from the signals operates an electroexplosive device in the ASD; the device removes the second lock from the rotor. A logic circuit packaged with the target detecting device (TDD) electronics recognizes the high-amplitude coincident signals obtained in a gun firing.

With the spring cocked and both locks removed from the rotor, the rotor is driven to the in-line position at a rate controlled by the urging of the spring and the damping of the untuned escapement. When the rotor reaches the in-line position, the detonator is connected to the firing circuit.

In greater detail (fig. 5), the leaf mechanism consists of three sequentially operating leaves. The shaft of the third leaf is one lock on the rotor. The second leaf cocks the spring that drives the rotor. The first leaf and its spring are added for additional drop safety. The spring on the first leaf is anchored to the leaf mechanism frame. The spring is precocked to provide an initial bias on the leaf. Launch acceleration must rotate the first leaf against the linearly increasing torque of the spring to release the second leaf. The spring on the second leaf has no prewind so as not to place stored energy on the rotor, but launch acceleration must rotate the second leaf against the linearly increasing spring torque to release the third leaf. Launch acceleration must then rotate the third leaf and its shaft to cause the third leaf to lock the second leaf down and allow the shaft of the third leaf to release the rotor.

The muzzle exit signal from the induction sensors operates an electroexplosive piston actuator to disengage a flat steel lock from the rotor.

The rotor turns 90 deg to the in-line position. The arming delay is obtained from the first 45 deg of rotation by the damping of the escapement. The rotor then snaps through the remaining 45 deg to the in-line position. When the rotor reaches the in-line position, the detonator terminals on the rotor mate with contacts on the contact board. A spring-loaded slide bolt locks the rotor in the armed position.

The contacts on the board are connected to the TDD by flexible cabling on the inside wall of the warhead. The piston actuator is always connected to the induction sensor logic circuit, but the detonator is not connected to the TDD firing circuit until the rotor reaches the in-line position.

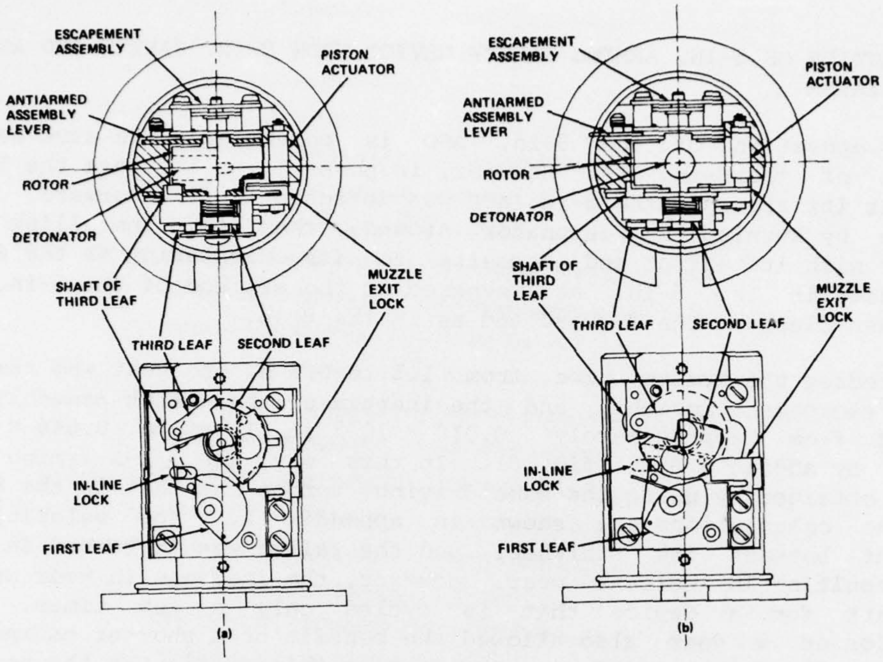



Figure 5. Arming safety device in (a) safe and (b) armed conditions.

The detonator is the Army M84 wire-bridge electric detonator. The piston actuator is the Atlas 1MT172. The 1MT172 has a wire bridge and is the only commercially available piston actuator that can be fired by using only the energy from the muzzle exit sensors. Also, the small size and push type of output of the actuator make the actuator suitable for incorporation in the space available in the ASD. The piston actuator is always connected to its firing circuit. If the piston actuator functions prior to launch, a sequencing pin is moved into engagement with the leaf mechanism to prevent removal of the setback lock and to dud the ASD.

The enclosing can covers the top and sides of the ASD to prevent the impingement of particles and gasses on the warhead explosive if the electric detonator should function unintentionally prior to arming. The can also supports the lead charge and booster pellet. The lead charge is housed in a steel liner and protected by a steel diaphragm at the input end. A cap covers the booster pellet. Both the lead charge and the booster pellet are pressed RDX Composition CH-6.

The ASD is assembled in the safe condition. However, since operability tests are a normal portion of the manufacturing process, a lever has been incorporated to prevent installation of an armed ASD into its can.

4. EVOLUTION OF 5-IN. ARMING SAFETY DEVICE FROM 8-IN. SAFETY AND ARMING MECHANISM

The operation of the 5-in. ASD is essentially the same as the operation of the 8-in. S&A. However, in phase I, to initiate the 5-in. warhead at its aft end, the 5-in. ASD was designed to fire forward. This was done by turning the detonator around, that is, installing the detonator with its output end opposite to its orientation in the 8-in. The contacts in the 5-in. are recessed at the aft end of the 5-in. ASD rather than flush at the forward end as in the 8-in.

To reduce the arming time from 1.5 to 0.5 s, one gear was removed from the escapement assembly, and the inertia of the pallet assembly was increased from approximately $0.018 \times 10^{-6}$ in.-lb $s^2$ to $0.046 \times 10^{-6}$ in.-lb $s^2$ by adding a disk (fig. 6). In this way, the 1/2-s arming time could be obtained by using the same driving torque as that in the 8-in. S&A. The calculations are shown in appendix A. The velocity of engagement between the starwheel and the pallet was increased in the 5-in., resulting in increased wear. However, the increase in wear is not significant for a device that is cycled only a few times. The elimination of a gear also allowed the benefit of a shorter escapement stack (fig. 7), which aided in avoiding a thin section in the housing near the recessed aft contact board. The short stack was fastened together with staked posts through hollow bushings rather than with hollow bushings alone, and the mounting screws were relocated to the outer plate alone, forward and aft of the stack itself.

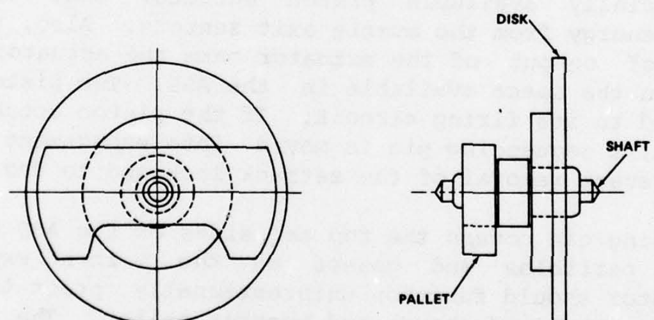



Figure 6. Disk added to pallet assembly to increase inertia.

To enable the leaf mechanism to respond to a 1000-g peak launch from the 155-mm howitzer, the stiffness of the spring on the first leaf had to be roughly half that in the 8-in. Also, at first it appeared that the second leaf would have to be enlarged to cock the rotor drive spring in the 1000-g peak launch, since the spring torque could not be reduced if

the escapement were to be driven reliably. However, an examination of the 8-in. design showed that the average spring bias on the second leaf in the 8-in. is less than half the average spring bias on the first leaf. In fact, the second leaf and spring would respond to a 1000-g launch without modification.

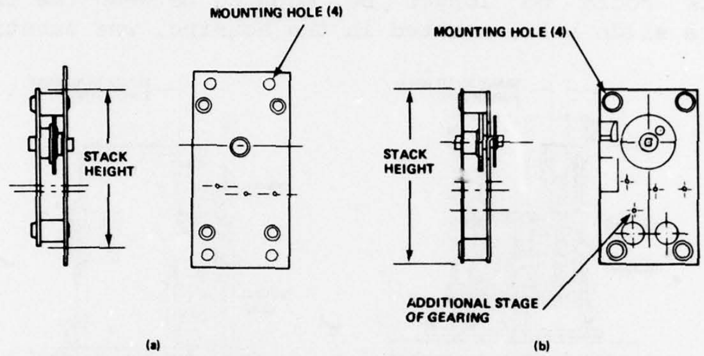



Figure 7. Shorter escapement assembly: (a) arming safety device and (b) safety and arming mechanism.

Reducing the bias on the first leaf does reduce the drop safety from the level of the 8-in. However, the 8-in. has a calculated drop safety of 83 ft (25.30 m), so that halving the bias on one leaf or even both leaves would not reduce the drop safety to less than 40 ft (12.19 m). The calculated drop safety for the 5-in. is presented in appendix B for the final leaf and spring designs.

Configuring the 5-in. ASD to the smaller diameter had a number of consequences:

a. The spring on the second leaf had to be shorter (fig. 8). Since the spring must provide 2.5 in.-oz as in the 8-in., and since we did not want to reduce wire size because of stresses, the number of coils was reduced, and the coil diameter was increased. This increased coil diameter necessitated the addition of a bushing to the second leaf shaft to center the spring. The spring on the first leaf was made shorter, also. This shortening was possible without increasing the coil size because it was to be a softer spring--hence, reduced wire size sufficed to shorten the spring.

b. The leaf mechanism had to be repackaged with a narrow outer plate (fig. 9). The hollow standoffs of the 8-in. were converted to smaller solid standoffs, and the mounting screws were relocated to the outer plate alone, forward and aft of the stack itself. The 5-in. had to

be a little longer to provide this mounting. There was insufficient space to pivot the third leaf in the outer plate of the 5-in. without violating the diameter. Thus, the third leaf was pivoted on a block that was attached to the inner plate. It was necessary also to reduce the size of the third leaf at the point where it attached to its shaft, making a difficult joint between the leaf and its shaft. Moreover, the in-line lock could no longer be mounted between the inner and outer plates, and a slide bolt, mounted in the housing, was substituted.

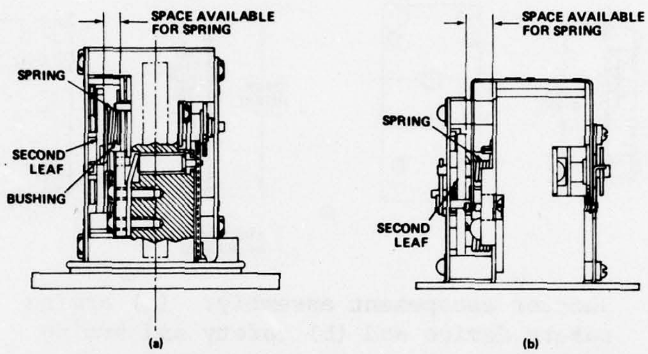



Figure 8. Configuring spring for second leaf: (a) arming safety device and (b) safety and arming mechanism.

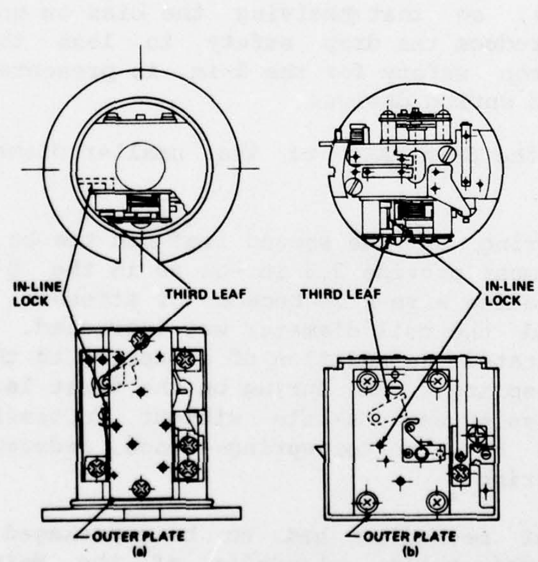



Figure 9. Packaging leaf mechanism: (a) arming safety device and (b) safety and arming mechanism.

c. The point of mounting of the muzzle exit lock could not be located outboard of the piston actuator, so it was located below it, and the bend line was rotated 90 deg from that in the 8-in. (fig. 10). Inability to put the mounting point outboard of the actuator made extraction of the lock more difficult. It was not possible to move the piston actuator inboard because clearance must be allowed for the terminals on the rotor. Also, as a result of the limited space, it was not possible to mount a telemetry contact for the muzzle exit lock. This had been present in the 8-in.

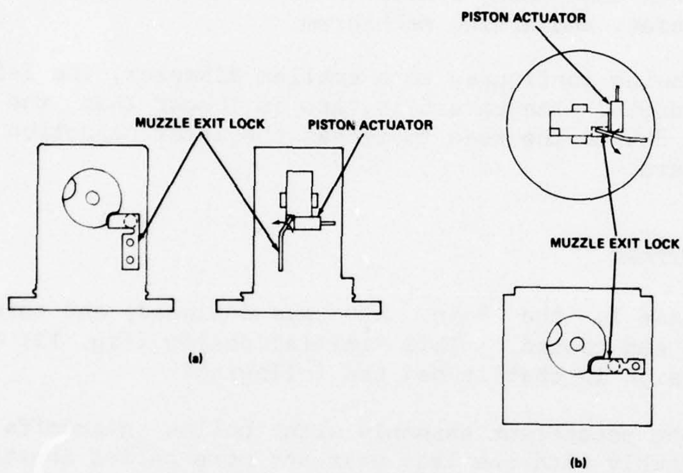



Figure 10. Location of muzzle exit lock: (a) arming safety device and (b) safety and arming mechanism.

d. The lock sequencing feature had to be implemented differently (fig. 11). The 8-in. has a sequencing pin mounted between the leaf mechanism plates, and it has a lever on the leaf mechanism to block motion of the pin until setback occurs. Thus, the lever prevents extraction of the muzzle exit lock if the piston actuator functions prior to setback. On the 5-in., the pin could not be mounted between the plates without violating the diameter. So it was mounted in the retainer for the piston actuator, and its motion was designed to lock up the second leaf if the piston actuator fired before setback had occurred. This design permitted extraction of the muzzle exit lock, but prevented removal of the setback lock if the piston actuator functioned prior to setback. The second leaf radius was enlarged to block the pin in the safe position. A cutout was added to the leaf to provide clearance for pin motion in the armed position, and a lightening hole was added to counteract the cutout's effect on the center of gravity of the leaf.

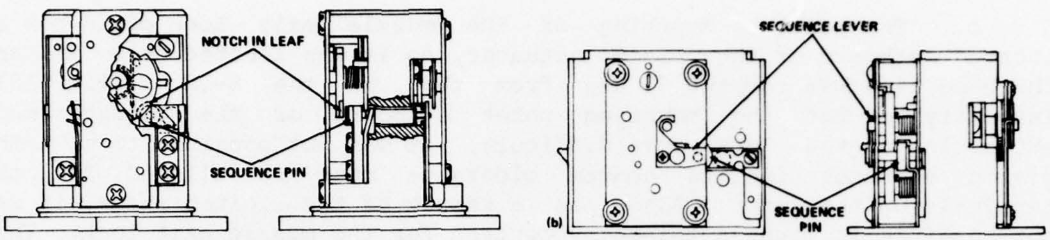



Figure 11. Lock sequencing feature: (a) arming safety device and (b) safety and arming mechanism.

Besides being configured to a smaller diameter, the 5-in. ASD was extended in length. The bare 5-in. ASD is longer than the bare 8-in. S&A, primarily due to the need to recess the interconnection terminals on the contact board.

## 5. PHASE I EFFORT

During phase I, the 5-in. ASD was designed, and three prototypes were assembled and tested. This initial design (fig. 12) differed from the present design in that it had the following:

a. A long escapement assembly with hollow standoffs (the 8-in. escapement assembly with one less gear and more pallet inertia)

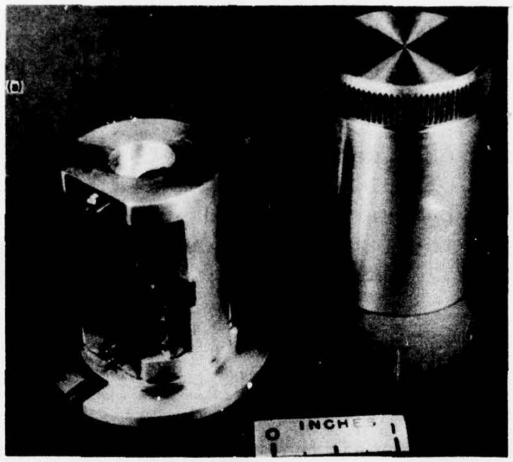
b. A built-up leaf mechanism in which the standoffs were not staked and both plates were mounted to the housing

c. A contact board with relatively long contact strips and a multipiece termination for the piston actuator

d. A muzzle exit lock retainer assembly that was relatively flexible

e. An aluminum lead charge cup

Assembly of the three prototypes revealed the need to bush the second leaf shaft to center the spring and keep it anchored. After the spring was anchored, the three prototypes were tested on the centrifuge for nonarming at 375 g and arming at 850 g. This test was the basis for establishing the 850-g specification limit for arming. Arming time was measured on the bench and found to be 0.6 to 0.8 s. The centrifuge and arming time tests also showed that the ground strip on the contact board was interfering with the motion of the rotor near the in-line position.



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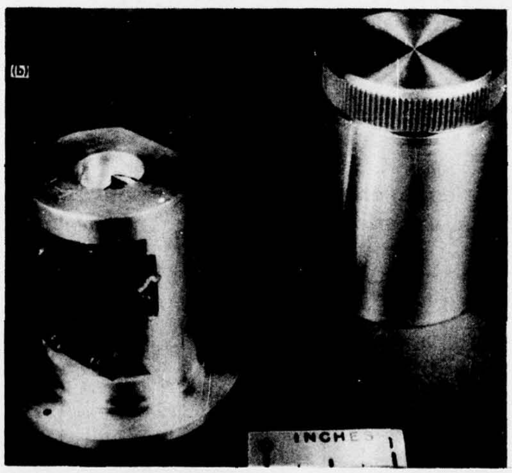

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Figure 12. Initial design of arming safety device: (a) front and (b) back.

A single unit was tested twice for operability of the muzzle exit lock. The lock was extracted, but the clearance with the rotor was marginal, the retainer was deformed, and the mounting screws were bent.

Ability of the hardware to withstand its own inertial loads at 8000 g was tested by mounting the ASD in a vehicle and performing an impact test. Although there was no structural damage, the third leaf did manage to slip by the cam on the shaft of the second leaf. This slipping suggested the need for greater nominal overlap between the third leaf and the cam.

Explosive train work was limited to verification of the ability of the detonator to initiate the lead charge in mockup hardware at ambient temperature. Ten leads of CH-6 and ten leads of A5 were initiated "high order" in the test. The gap between the detonator and the lead charge was 0.075 in. (0.19 cm). The CH-6 was selected over the A5 as the design material simply because CH-6 was acceptable to both the Army and the Navy per the current issue of MIL-STD-1316. (The selection of CH-6 was made before A5 was accepted by the Navy.) The lead charges differed from the present design in that the explosive was contained in an aluminum cup mounted in a steel liner, rather than directly contained in a closed-end steel liner.

## 6. PHASE II EFFORT--OVERVIEW AND INITIAL DESIGN REFINEMENTS

The phase II effort consisted of initial design refinements to eliminate problems encountered in phase I, fabrication of 35 ASD's and a greater number of explosive train mockups, a series of preliminary qualification tests, and further design refinements suggested by experience with assembly and test of the qualification units.

The initial design refinements are listed below and are retained in the final design:

a. Modifying the escapement plate and post design to convert to the present staked posts and mounting holes in the outer plate (fig. 13)

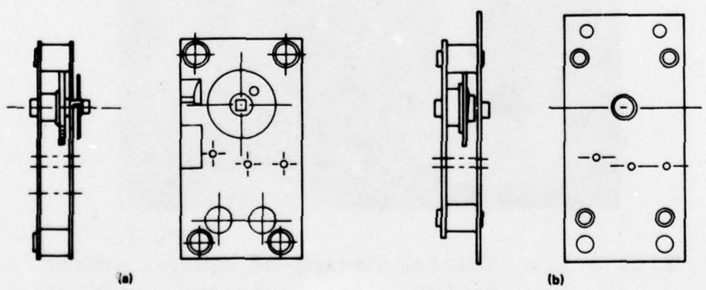


Figure 13. Escapement assembly design refinement:
(a) phase I and (b) phase II and present.

b. Modifying the electrical contact design to utilize the present shorter contact strips for the detonator and ground and to preclude interference of the ground contact with the rotor near the armed position (fig. 14)

c. Determining the proper hardness for the muzzle exit lock

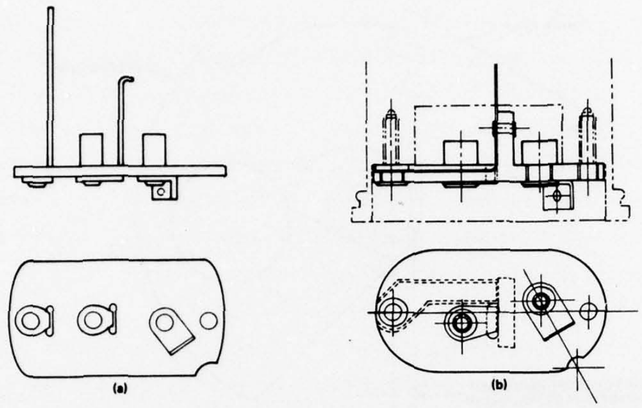


Figure 14. Contact board design refinement: (a) phase I and (b) phase II.

d. Improving the fastening of the retainer for the muzzle exit lock by converting from 0-80 screws to the present 2-56 screws (fig. 15) (The retainer had to be thinned down to keep the larger screw heads within the diameter of the ASD.)

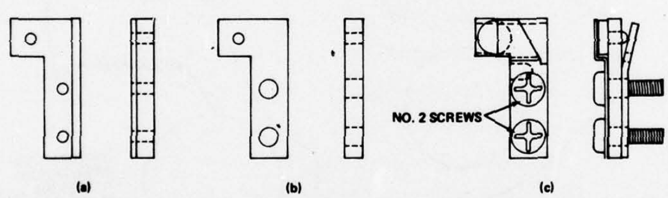


Figure 15. Improved fastening of retainer: (a) phase I retainer, (b) phase II retainer, and (c) phase II retainer fastening.

e. Increasing the overlap between the third leaf and the shaft of the second leaf in the safe position to prevent the third leaf from slipping by the second leaf shaft (fig. 16)

f. Reducing the clearance between the third leaf and the second leaf shaft in the armed position to control the armed position of the second leaf (fig. 17) (This was necessary to assure clearance for motion of the lock sequencing pin after the leaf mechanism had experienced setback.)

g. Modifying the housing design and the housing/can interface for greater strength and simplicity (fig. 18) (Dimensions were adjusted to assure that the can and booster cap were properly supported to withstand the possible load of the warhead explosive in a gun launch. The housing's load carrying ability was improved by reducing the size of the recess for the contact board.)

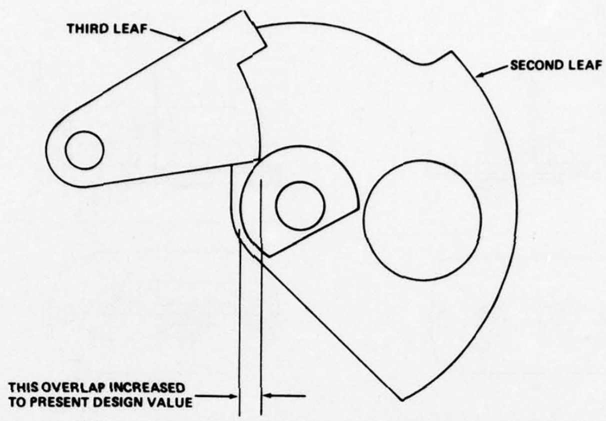


Figure 16. Increased overlap of third leaf with cam on second leaf shaft in safe position.

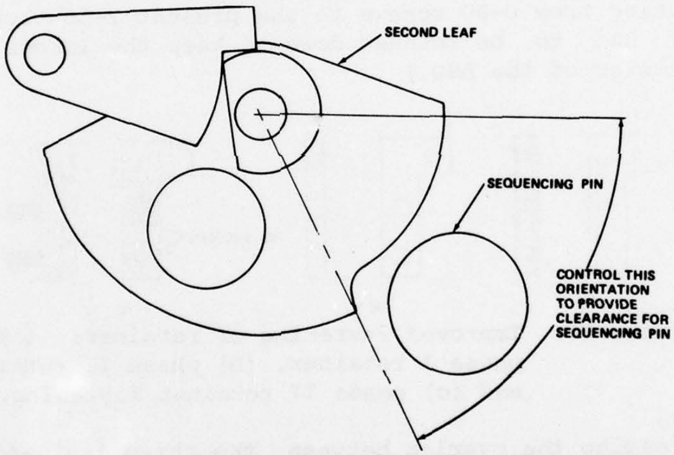


Figure 17. Improved positioning of second leaf in armed position.

In addition to simply drawing up the initial design refinements, some empirical work was done. Preliminary tests of a mechanism with the redesigned contact board indicated that the rotor drive spring was adequate to close the contacts on the bench. Since the projectile is outside the gun when the spring drives the rotor, the bench test was thought to be of adequate similitude.

To determine the proper hardness for the muzzle exit lock and to evaluate the improved fastening for the retainer, locks hardened to RC39 and locks hardened to RC55 were tried out with the new retainers. Locks of hardness RC55 worked well in the absence of the lock sequencing pin. The piston motor force extracting the muzzle exit lock deformed the

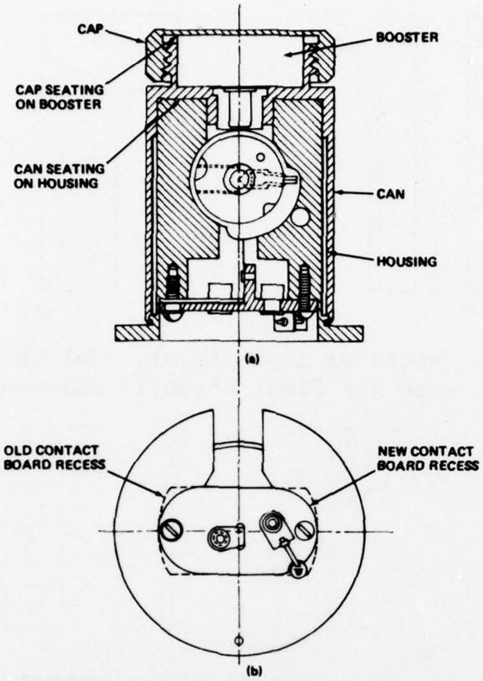


Figure 18. Structural improvements: (a) stackup seating and (b) contact board recess.

retainer for the lock and thereby allowed more travel by the muzzle exit lock. However, when the lock sequencing pin was present, the deformation of the retainer put the pin askew to the line of action of the muzzle exit lock. The askew pin loaded down the lock, so the lock only marginally cleared the rotor.

Two steps were taken to alleviate the problem. First, the retainer was changed from 303 stainless to hardened 17-4 PH stainless to improve rigidity, and a relief was added to the inboard side of the retainer to permit the same lock travel that would have resulted from retainer deformation (fig. 19). This is the present design. Second, the two notches in the muzzle exit lock were converted to a single notch in the inboard edge to improve the leverage of the piston actuator on the lock (fig. 20). This also is the present design.

Dimensions were changed to assure that the shoulder in the can could bear on the top of the housing and that the booster cap could bear on the booster pellet. Before all units were modified, a single unit was so configured and subjected to an impact test at 8000 g in an air gun with simulated explosive bearing on the ASD. The unit showed no structural damage.

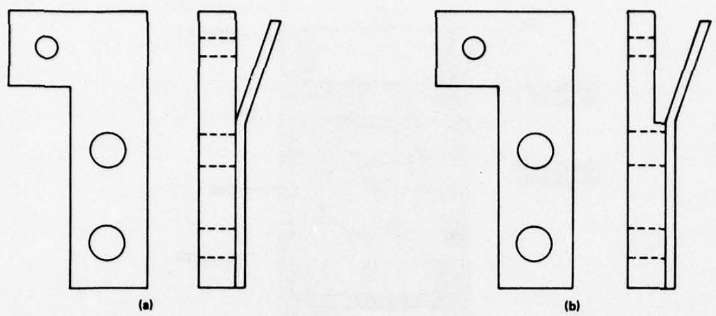


Figure 19. Retainer improvement: (a) early phase II and (b) final phase II and present.

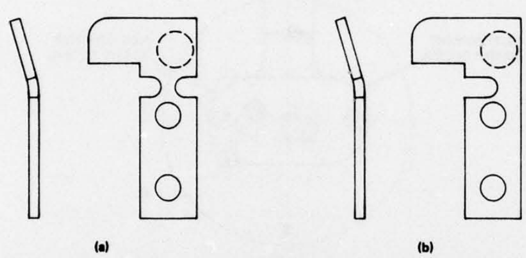


Figure 20. Muzzle exit lock improvement: (a) phase I and early phase II and (b) final phase II and present.

However, examination of a sample ASD revealed a new problem. The enclosing can was perilously close to interfering with the leaf mechanism and the escapement assembly. Consequently, the inside diameter of an enclosing can was increased by 1/16 in. (0.16 cm) along most of its length (as in the present design) to allow adequate clearance even when the tolerance buildup would be unfavorable (fig. 21). The planned out-of-line safety tests would have to show whether the reduction of wall thickness by 1/32 in. (0.08 cm) would lead to fragment ejection in the out-of-line mode.

Prior to the planned out-of-line tests, a preliminary out-of-line test with two mockups revealed the inability of the aluminum lead cup to resist perforation during 45 deg out-of-line functioning of the detonator. Consequently, the aluminum lead cup was eliminated, and a steel part called the "liner" was redesigned to house the lead charge explosive directly and protect it with a steel diaphragm 0.010 in. (0.025 cm) thick where the closed end of the aluminum cup used to be (fig. 22). This steel diaphragm was not perforated in a one-unit check test. Also, in a one-unit, in-line check test with the steel diaphragm, the diaphragm did not adversely affect in-line propagation. The redesigned liner is the present design.

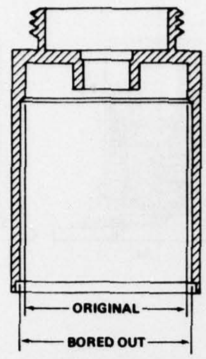


Figure 21. Increased inside diameter of sleeve.

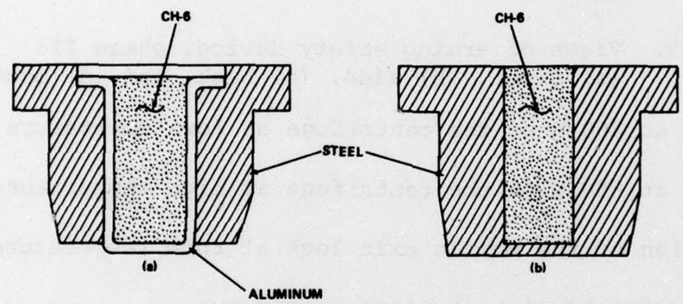


Figure 22. Lead charge improvement: (a) phase I and (b) phase II and present.

After those design refinements were incorporated, the phase II ASD (fig. 23, p. 26) differed from the present design in that the leaf mechanism still was built up on the housing, rather than staked together as a modular assembly, and the termination for the piston actuator still was a multipiece design.

## 7. PHASE II EFFORT--QUALIFICATION TESTS AND SUBSEQUENT DESIGN REFINEMENTS

Most of the ASD parts were machined by a local vendor and inspected at his facility. The other parts were machined and inspected at HDL. The ASD was assembled entirely at HDL, following the sequence of figure 24. The test series for these ASD's consisted of the following:

a. Nonarming at 375 g and arming at 850 g on the centrifuge

b. Arming time

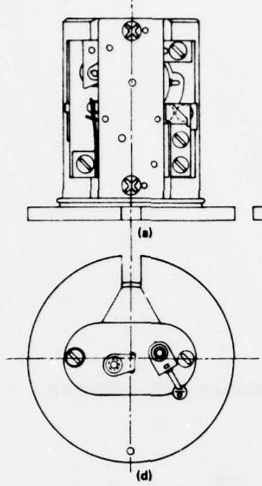


Figure 23. Views of arming safety device, phase II: (a) front, (b) side, (c) back, and (d) bottom.

c. Arming at 850 g on the centrifuge at low temperature

d. Arming at 850 g on the centrifuge at high temperature

e. Operation of the muzzle exit lock at room temperature

f. Impact structural test using an air gun

g. "Hydrostatic pressure" test to verify the ability of the ASD to carry the load of the warhead explosive above it during gun launch

h. Recovery firings in 81-mm mortar projectiles at the HDL Test Area, Blossom Point, MD

i. Recovery firings from Navy guns at proof acceleration

j. 40-ft (12.19-m) drop test

k. Out-of-line safety tests with units from the recovery firings and the drop tests

In addition, approximately 18 in-line explosive train mockups were subjected to a Bruceton statistical test in which the air gap between the detonator and the lead charge was the variable. Ten more in-line mockups were subjected to a confirmatory test at low temperature in which the gap between the detonator and lead charge was the maximum allowed by the design. Twenty out-of-line mockups were subjected to a Varicomp test in which the lead charges were PETN, which is much more sensitive than the CH-6 actually used in the lead charge. A flow diagram for the test series on actual ASD's and mockups is shown in figure 25.

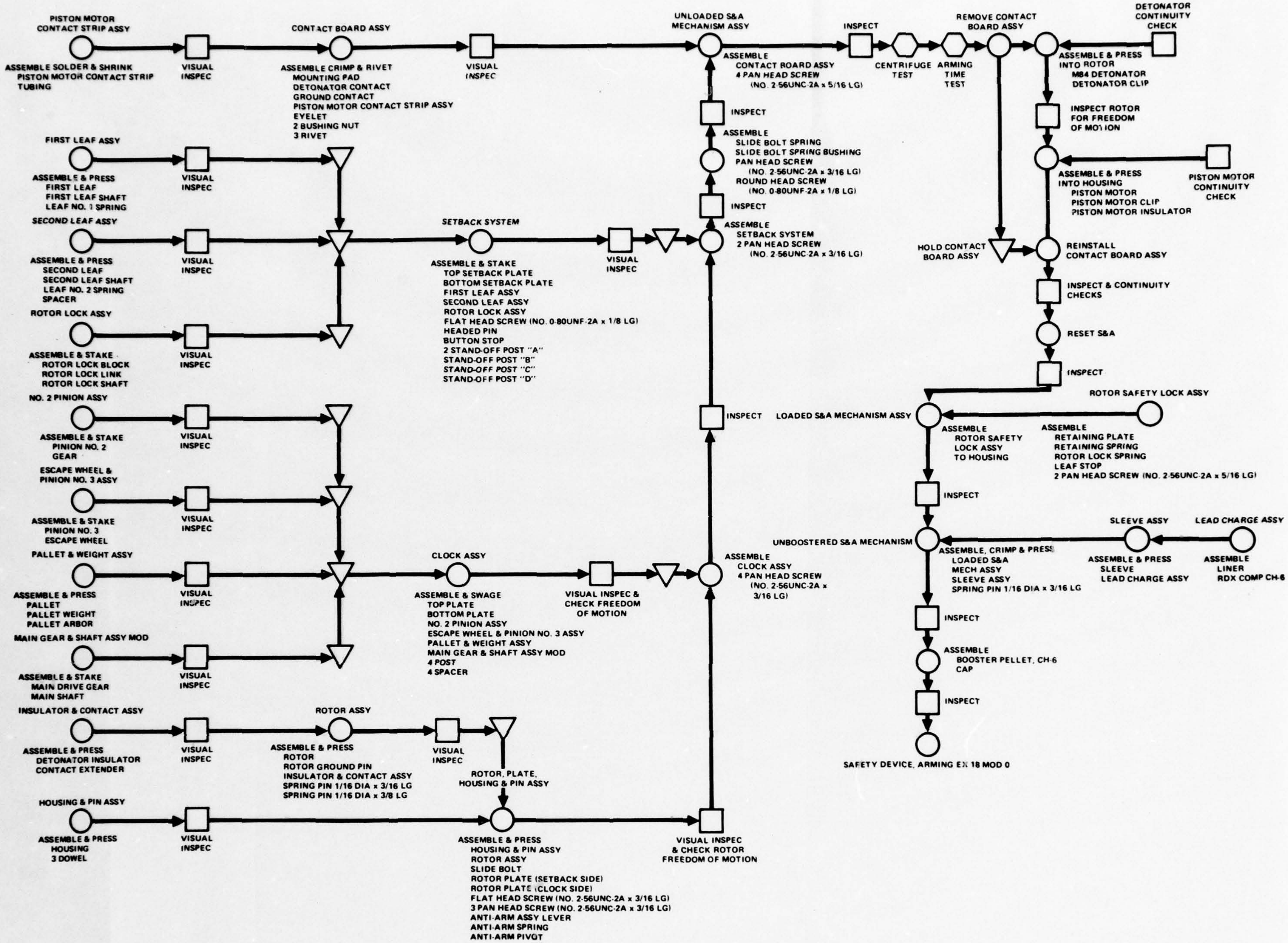


Figure 24. Assembly flow diagram of arming safety device.

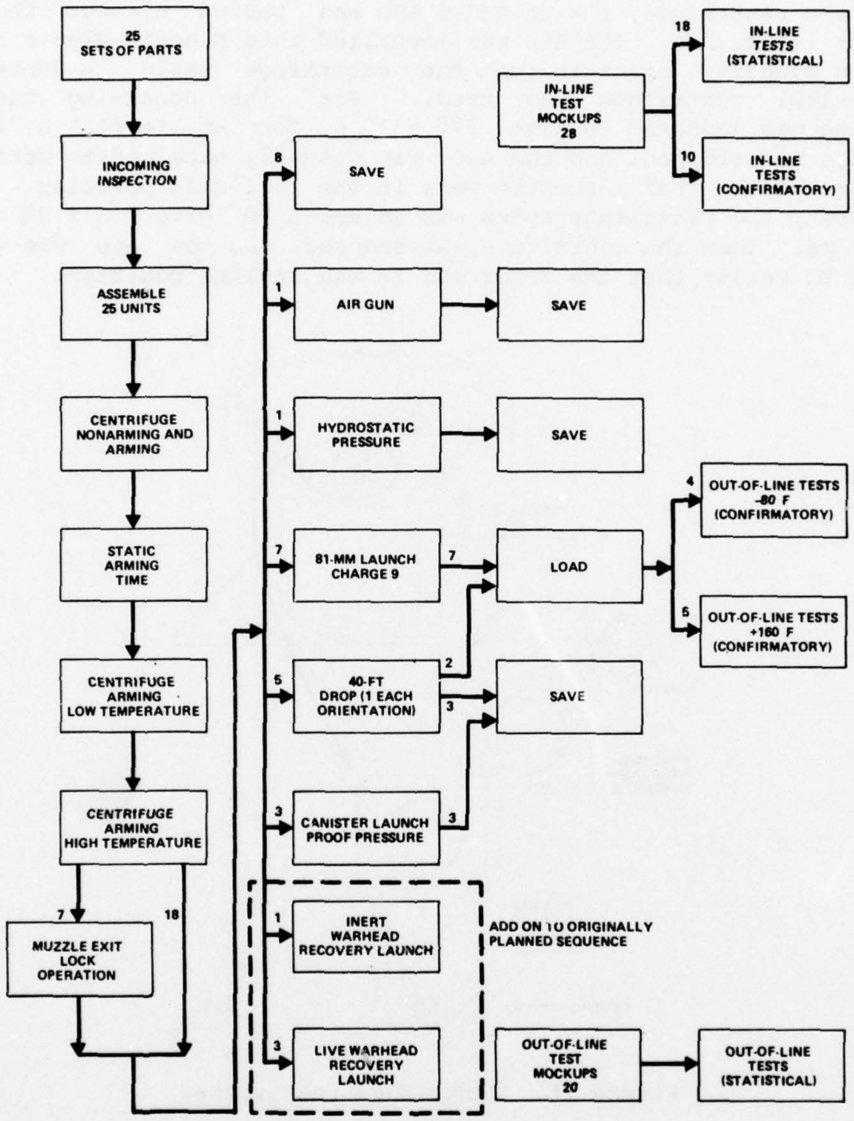


Figure 25. Qualification test sequence.

Thirty-five ASD's were assembled, and the qualification test sequence was begun. (Only 25 ASD's were required for the qualification tests, but 35 were assembled to allow for some fallout in the early stages of the testing or for repetition of tests.) The 35 ASD's were subjected to centrifuge nonarming at 375 g, centrifuge arming at 850 g, and static arming time tests at room temperature. Following these tests, the 35 units were subjected to centrifuge arming at 850 g at +160 and -65 F (71 and -54 C).

On the centrifuge, the unloaded ASD was tested without the muzzle exit lock (fig. 26). The ASD was installed in a plastic sleeve and then placed in mounting brackets on the centrifuge table. A Genisco part No. 1078-1301 centrifuge was used. For the nonarming test, the centrifuge was adjusted to give 375 ± 10 g for at least 1 s; then the centrifuge was stopped, and the ASD was visually examined to verify that the rotor and the leaf mechanism were in the full safe position. For the arming test, the centrifuge speed was adjusted to give 850 ± 25 g for at least 15 ms. Then the centrifuge was stopped, and the ASD was visually examined to verify that the rotor was in the in-line position.

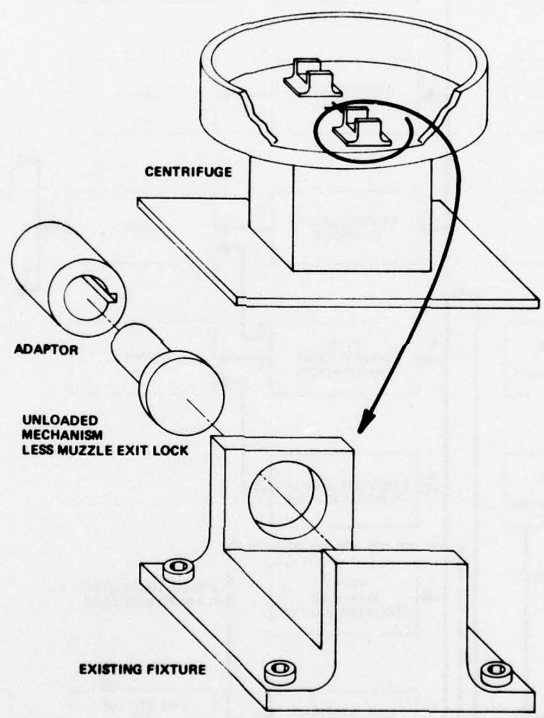


Figure 26. Centrifuge test setup.

To perform the arming time test, an armed unloaded ASD, less muzzle exit lock, was fitted with a dummy detonator. This assembly was placed in a cradle (fig. 27), the rotor was moved to the safe position, and a release pin was pushed into the second lock notch in the rotor. When the release pin was extracted, an electronic counter was started, and when the rotor reached the armed position, the counter was stopped. A Hewlett-Packard HP5233L counter was used. To pass the test, the time had to be 0.5 to 1.0 s, and the rotor had to be locked in the in-line position.

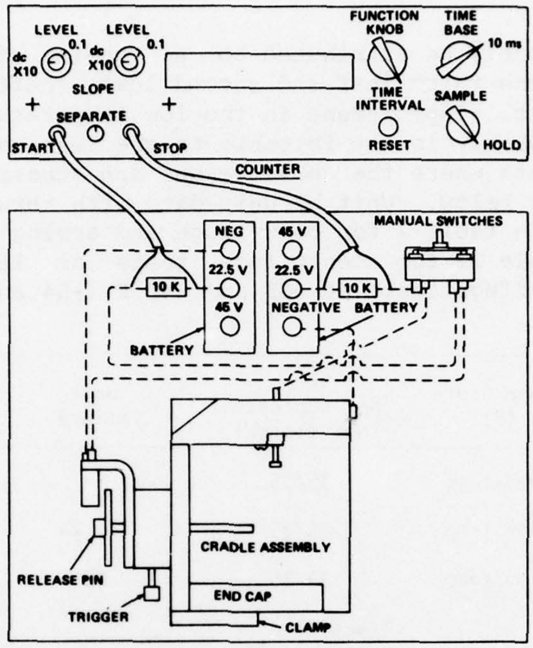


**Figure 27. Arming time test setup.**

**The results of the centrifuge and arming time tests are summarized below.**

| Test | Temperature (F) | Score (No. successes/ No. tested) | Unit failure | Mode of failure |
|---|---|---|---|---|
| Nonarm at 375 g | Room temp | 35/35 | -- | -- |
| Arm at 850 g | Room temp | 31/35 | 8, 15, 25, 28 | Third leaf not down |
| Arming time | Room temp | 34/35 | 25 | Not fully in line |
| | | Times were 0.53 to 0.89 s with av = 0.69 s | | |
| Arm at 850 g | +160 | 33/35 | 8, 28 | Third leaf not down |
| Arm at 850 g | -65 | 28/35 | 4, 8, 9, 15, 17, 28, 39 | Third leaf not down |

**The four units that failed at room temperature were rerun, and only two failed the second time (units 8 and 28). The seven units that failed at -65 F (-54 C) were rerun at -40 F (-40 C), and only three failed (units 8, 28, and 39). Improvement in the room temperature performance in the**

second run can probably be attributed to a run-in effect where surface irregularities on the third leaf and second leaf shaft were removed by exercising the unit. Improvement in the low temperature performance in the second run probably is attributable to the less severe temperature. A summary of the data where the above reruns are substituted for previous failures is given below. Unit by unit data with reruns substituted for failures is shown in table I for centrifuge and arming time tests at room temperature, in table II for centrifuge tests at 160 F (71 C), and in table III for centrifuge tests at -65 and -40 F (-54 and -40 C).

| Test | Temperature (F) | Score (No. successes/ No. tested) | Unit failure | Mode of failure |
|---|---|---|---|---|
| Nonarm at 375 g | Room temp | 35/35 | -- | -- |
| Arm at 850 g | Room temp | 33/35 | 8, 28 | Third leaf not down |
| Arming time | Room temp | 34/35 | 25 | Not fully in line |
| | | Times were 0.53 to 0.89 s with av = 0.69 s | | |
| Arm at 850 g | +160 | 33/35 | 8, 28 | Third leaf not down |
| Arm at 850 g | -40 or -65 | 32/35 | 8, 28, 39 | Third leaf not down |

Based on the above data, units 8, 25, 28, and 39 were considered defective and were examined to determine the cause of failure. This examination did not interfere with the qualification tests, because only 25 units were required for qualification.

In each of the four units that failed to arm, the spacing washer on the clock side of the rotor pivot was removed. Then the units were retested. All but one unit worked properly. In that unit, failures still occurred occasionally, and it was necessary to replace the spring on the second leaf, as well as to remove the rotor washer to obtain proper operation. In these four units, the spacing washer was apparently positioning the rotor so as to load down the third leaf where the third leaf shaft engages the rotor. (The washer had been used in the first place to take up excessive end shake in the rotor. End shake in these four units was apparently less than in other units.)

TABLE I. CENTRIFUGE AND ARMING TIME TESTS AT ROOM TEMPERATURE

| Unit No. | Nonarming 375 g | Arming 850 g | In-line lock | Antiarmed assembly | Arming time 0.5 to 1.0 s | In-line lock (static) | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | OK | OK | OK | OK | 0.580 | OK | |
| 2 | OK | OK | OK | OK | 0.640 | OK | |
| 3 | OK | OK | OK | OK | 0.840 | OK | |
| 4 | OK | OK | OK | OK | 0.890 | OK | |
| 5 | OK | OK | OK | OK | 0.750 | OK | |
| 6 | OK | OK | OK | OK | 0.620 | OK | |
| 7 | OK | OK | OK | OK | 0.660 | OK | |
| 8 | OK | Failed | -- | -- | 0.760 | OK | Failed previous centrifuge test at room temp |
| 9 | OK | OK | OK | OK | 0.740 | OK | |
| 10 | OK | OK | OK | OK | 0.610 | OK | |
| 11 | OK | OK | NO | OK | 0.770 | OK | |
| 12 | OK | OK | OK | OK | 0.670 | OK | |
| 13 | OK | OK | NO | OK | 0.530 | OK | |
| 14 | OK | OK | OK | OK | 0.680 | OK | |
| 15 | OK | OK | OK | OK | 0.730 | OK | Failed previous centrifuze test at room temp |
| 16 | OK | OK | OK | OK | 0.680 | OK | |
| 17 | OK | OK | OK | OK | 0.640 | OK | |
| 18 | OK | OK | NO | OK | 0.800 | OK | |
| 19 | OK | OK | OK | OK | 0.670 | OK | |
| 21 | OK | OK | OK | OK | 0.630 | -- | |
| 22 | OK | OK | OK | OK | 0.580 | -- | |
| 23 | OK | OK | OK | OK | 0.730 | OK | |
| 24 | OK | OK | NO | OK | 0.680 | -- | |
| 25 | OK | OK | NO | OK | Failed | Failed | Failed previous centrifuge test at room temp |

TABLE I. CENTRIFUGE AND ARMING TIME TESTS AT ROOM TEMPERATURE (Cont'd)

| Unit No. | Nonarming 375 g | Arming 850 g | In-line lock | Antiarmed assembly | Arming time 0.5 to 1.0 s | In-line lock (static) | Remarks |
|---|---|---|---|---|---|---|---|
| 26 | OK | OK | OK | OK | 0.770 | OK | |
| 27 | OK | OK | NO | OK | 0.670 | OK | |
| 28 | OK | Failed | -- | -- | 0.700 | OK | Failed previous centrifuge test at room temp |
| 29 | OK | OK | NO | OK | 0.710 | OK | |
| 32 | OK | OK | OK | OK | 0.650 | OK | |
| 33 | OK | OK | OK | OK | 0.670 | OK | |
| 35 | OK | OK | OK | OK | 0.670 | OK | |
| 36 | OK | OK | NO | OK | 0.530 | OK | |
| 37 | OK | OK | OK | OK | 0.830 | OK | |
| 38 | OK | OK | OK | OK | 0.640 | OK | |
| 39 | OK | OK | OK | OK | 0.760 | OK | |

*Note: Range of times: 0.53 to 0.89 s; av: 0.69 s.*

The muzzle exit lock operability tests were conducted. In these tests, the piston actuator and the muzzle exit lock were installed in the unloaded ASD. Then the leaf mechanism was armed either manually or on the centrifuge and, following arming, the piston actuator was fired. Examination of ASD's prior to testing showed that there was inadequate clearance for movement of the lock sequencing pin in many of the units. The clearance was inadequate because the angular displacement of the second leaf in the armed position was somewhat less than intended, despite the design refinement, due to either tolerance buildup or dimensional discrepancies. For this test, seven units with adequate clearance were selected, and the lock operated properly with the lock sequencing pin present. Unit by unit data are shown in table IV. The lock sequencing pin was omitted from those units on hand where the clearance was inadequate. Further improvement in locating the third leaf seems necessary to assure the proper armed position for the second leaf.

Some loading of the muzzle exit lock by the lock sequencing pin was still evident, and it may be possible to reduce the loading further by changing from a steel pin to an aluminum pin. It also appears that the pin could be better piloted. Building up the outboard surface of the retainer would increase the length-to-diameter ratio of the pin mounting.

TABLE II. CENTRIFUGE TESTS AT HIGH TEMPERATURE (+160 F)

| Unit No. | Arming 850 g | In-line lock | Antiarmed assembly |
|---|---|---|---|
| 1 | OK | OK | OK |
| 2 | OK | OK | OK |
| 3 | OK | OK | OK |
| 4 | OK | OK | OK |
| 5 | OK | OK | OK |
| 6 | OK | OK | OK |
| 7 | OK | OK | OK |
| 8 | Failed | -- | -- |
| 9 | OK | OK | OK |
| 10 | OK | OK | OK |
| 11 | OK | NO | OK |
| 12 | OK | OK | OK |
| 13 | OK | OK | OK |
| 14 | OK | OK | OK |
| 15 | OK | OK | OK |
| 16 | OK | OK | OK |
| 17 | OK | OK | OK |
| 18 | OK | OK | OK |
| 19 | OK | OK | OK |
| 21 | OK | OK | OK |
| 22 | OK | OK | OK |
| 23 | OK | OK | OK |
| 24 | OK | OK | OK |
| 25 | OK | NO | OK |
| 26 | OK | OK | OK |
| 27 | OK | OK | OK |
| 28 | Failed | -- | -- |
| 29 | OK | OK | OK |
| 32 | OK | OK | OK |
| 33 | OK | OK | OK |
| 35 | OK | OK | OK |
| 36 | OK | NO | OK |
| 37 | OK | OK | OK |
| 38 | OK | OK | OK |
| 39 | OK | OK | OK |

TABLE III. CENTRIFUGE TESTS AT LOW TEMPERATURE

| Unit No. | Temp (2 hr) | Arming 850 g | In-line lock | Antiarmed assembly | Remarks |
|---|---|---|---|---|---|
| 1 | -65 | OK | OK | OK | |
| 2 | -65 | OK | OK | OK | |
| 3 | -65 | OK | OK | OK | |
| 4 | -40 | OK | OK | OK | Failed previous centrifuge test at -65 F |
| 5 | -65 | OK | OK | OK | |
| 6 | -65 | OK | OK | OK | |
| 7 | -65 | OK | OK | OK | |
| 8 | -40 | Failed | -- | -- | Failed previous centrifuge test at -65 F |
| 9 | -40 | OK | OK | OK | Failed previous centrifuge test at -65 F |
| 10 | -65 | OK | OK | OK | |
| 11 | -65 | OK | NO | OK | |
| 12 | -65 | OK | OK | OK | |
| 13 | -65 | OK | NO | OK | |
| 14 | -65 | OK | OK | OK | |
| 15 | -40 | OK | OK | OK | Failed previous centrifuge test at -65 F |
| 16 | -65 | OK | OK | OK | |
| 17 | -40 | OK | OK | OK | Failed previous centrifuge test at -65 F |
| 18 | -65 | OK | NO | OK | |
| 19 | -65 | OK | OK | OK | |
| 21 | -65 | OK | OK | OK | |
| 22 | -65 | OK | OK | OK | |
| 23 | -65 | OK | OK | OK | |
| 24 | -65 | OK | OK | OK | |
| 25 | -65 | OK | NO | OK | |

TABLE III. CENTRIFUGE TESTS AT LOW TEMPERATURE (Cont'd)

| Unit No. | Temp (2 hr) | Arming 850 g | In-line lock | Antiarmed assembly | Remarks |
|---|---|---|---|---|---|
| 26 | -65 | OK | OK | OK | |
| 27 | -65 | OK | OK | OK | |
| 28 | -40 | Failed | -- | -- | Failed previous centrifuge test at -65 F |
| 29 | -65 | OK | OK | OK | |
| 32 | -65 | OK | OK | OK | |
| 33 | -65 | OK | OK | OK | |
| 35 | -65 | OK | OK | OK | |
| 36 | -65 | OK | OK | OK | |
| 37 | -65 | OK | OK | OK | |
| 38 | -65 | OK | OK | OK | |
| 39 | -40 | Failed | -- | -- | Failed previous centrifuge test at -65 F |

TABLE IV. MUZZLE EXIT LOCK OPERABILITY TESTS AT ROOM TEMPERATURE

| Unit No. | Muzzle exit lock No. | Retainer No. | In-line lock | Muzzle exit lock operation | Rotor in line |
|---|---|---|---|---|---|
| 2 | 5 | 5 | OK | Proper | OK |
| 19 | 8 | 8 | OK | Proper | OK |
| 27 | 21 | 21 | OK | Proper | OK |
| 29 | 43 | 43 | OK | Proper | OK |
| 32 | 53 | 53 | OK | Proper | OK |
| 37 | 55 | 55 | OK | Proper | OK |
| 38 | 13 | 13 | OK | Proper | OK |

*Notes: 1. Tests done with muzzle exit locks No. 43 and 55 and five others selected at random; No. 43 and 55 were at the extremes of hardness (low and high).*

*2. Units were selected that exhibited a second leaf armed position that provided adequate clearance for the lock sequencing pin.*

The air gun test of the ASD in a fixture by itself was performed (fig. 28). As expected, there was no damage to the ASD in this test. The leaf mechanism locked down, but the third leaf did not rotate enough to release the rotor. (Lock down and rotor release are not requirements in tests performed in the air gun.) Then the third leaf was pushed down farther manually, and when the muzzle exit lock was removed from the rotor, the rotor armed. The unit was then reset and tested for proper operation on the centrifuge.

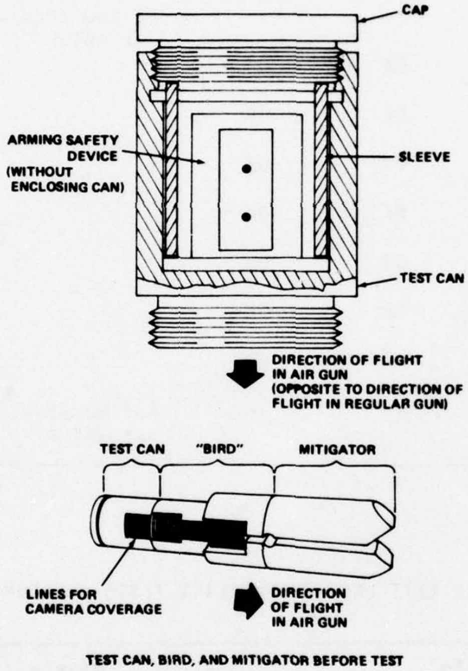


Figure 28. Air gun test fixture.

The so-called "hydrostatic pressure" test was conducted in the air gun with a simulated explosive load bearing on the ASD (fig. 29). The ASD was placed in its enclosing can for this test. A wax booster pellet was placed in the booster cavity. The peak acceleration load was 7800 g. The ASD was not damaged. The leaf mechanism had locked down. (Leaf lock down is not a requirement in this test, but sometimes occurs.) When the muzzle exit lock was removed from the rotor, the rotor armed. The ASD was reset and tested for proper operation on the centrifuge. The wax booster pellet also appeared to be in good condition. The pellet was in one piece and was not crushed. However, the pellet had been slightly indented by the staking marks around the lead charge. With the remainder of this hardware, no part of the stake was allowed to protrude into the booster cavity, and for the future, the lead charge liner will be press fitted into the can, rather than staked. This laboratory test provides

equal peak amplitude, but less duration, than the actual gun launch acceleration. However, in a gun launch of an actual warhead where the duration is greater, the explosive's internal strength reduces the column load being applied to the ASD.

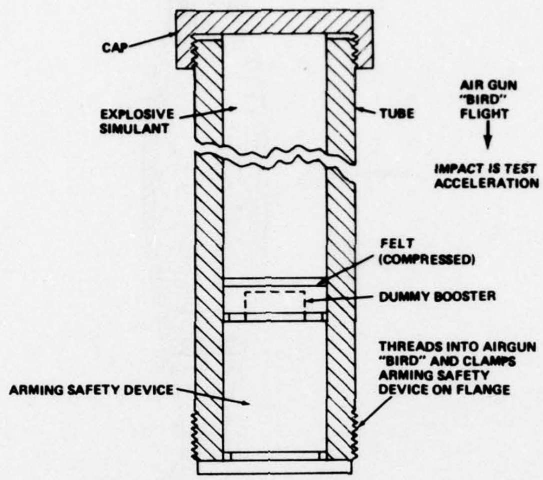


Figure 29. Fixture for air gun test with explosive simulant bearing on arming safety device.

The parachute recovery flights were conducted with five inert ASD's, less muzzle exit lock. Each ASD was mounted in a fixture atop an 81-mm mortar projectile (fig. 30). The projectiles were fired at 8000 g from a pack howitzer with a smooth-bore 81-mm barrel. All ASD's were recovered, and all rotors were locked in the armed condition as desired. Unit by unit data are shown in table V. Although all ASD's armed, the third leaf of the leaf mechanism was not down against its stop, except in one unit. That is, the third leaf had rotated far enough to lock the second leaf and far enough to release the rotor, but it had not rotated far enough to hit its stop. The third leaf does rotate to the stop in centrifuge tests and was expected to do so in the field, even though that much rotation is not a functional necessity. That the third leaf stopped short of the stop may be due to the relatively short duration of the launch acceleration in the 81-mm barrel. The launch acceleration would be of greater duration in a 5-in. Navy gun.

The 40-ft (12.19-m) drop test was conducted with five inert ASD's. Each ASD was placed in a fixture atop an inert-loaded 105-mm projectile (fig. 31). One projectile was dropped in each of five orientations. The recovered ASD's are shown in figure 32. The ASD's dropped exactly nose up, and those dropped exactly nose down survived in excellent condition. They were safe, and both locks still engaged the rotor. The rotor was properly engaged to the escapement.

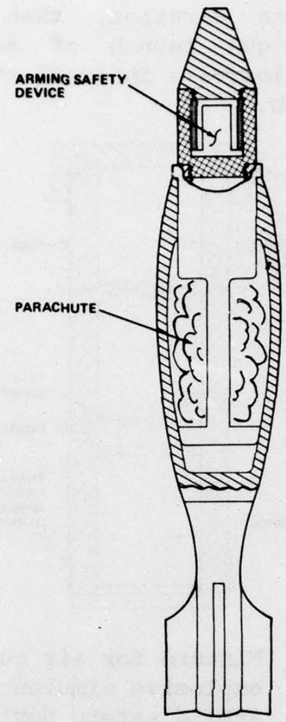


Figure 30. 81-mm vehicle for parachute recovery test.

The ASD's dropped in the other three orientations--nose up 45 deg, horizontal, and nose down 45 deg--sustained structural damage. The rotors were in the safe condition, but at least one of the two locks was no longer engaged. This disengagement was due to the rotor having bulged its bearing plates. This bulging allowed the rotor to get free of one or both locks. The rotors were not flopping around; but, in the unit dropped nose up 45 deg, it was possible to gradually arm the rotor by continually tapping the ASD on the bench. A significant amount of fastener backout was observed in this ASD and in the one dropped horizontally. Detailed raw data for this test are shown in table VI.

A rotor of aluminum, rather than steel, might eliminate the structural damage. However, some of the explosive tests described later would have to be repeated because changing the rotor material from steel to aluminum changes the confinement of the detonator. A retaining compound on the fasteners might eliminate backout, but the compound would have to be a dry patch, rather than a liquid, to avoid ASD contamination. Remedies for the drop test problems require further study. The question of whether the fixture and 105-mm projectile provided an overtest condition should also be addressed. The results of the 40-ft (12.19-m)

drop tests were discussed with a representative of NSWC/DL's Safety Branch. It was agreed that the rotor would be lightened later; specifically, an aluminum rotor would be tried out. This seems to be a step in the right direction, regardless of whether additional remedies are required.

TABLE V. UNITS AFTER PARACHUTE RECOVERY TEST IN 81-MM PROJECTILE

| Unit No. | Rotor position | In-line lock | Remarks |
|---|---|---|---|
| 3 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |
| 10 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |
| 14 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |
| 21 | Armed | Engaging rotor | Third leaf all the way down |
| 24 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |
| 33 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |
| 36 | Armed | Engaging rotor | Third leaf down far enough to lock second leaf and release rotor, but not all the way down |

A fixture for firing three ASD's in an 8-in. canister from the Mk71 gun was fabricated (fig. 33), and three ASD's were fired for parachute recovery. All ASD's armed. The third leaf of the leaf mechanism was down against its stop in each unit, and the rotor of each mechanism was locked in place.

Four series of explosive train tests were performed at NSWC/White Oak Laboratory (WOL) with hardware supplied by HDL: (1) statistical in-line tests (detonator to lead), (2) confirmatory in-line tests (detonator to lead to booster), (3) statistical out-of-line tests, and (4) confirmatory out-of-line tests.

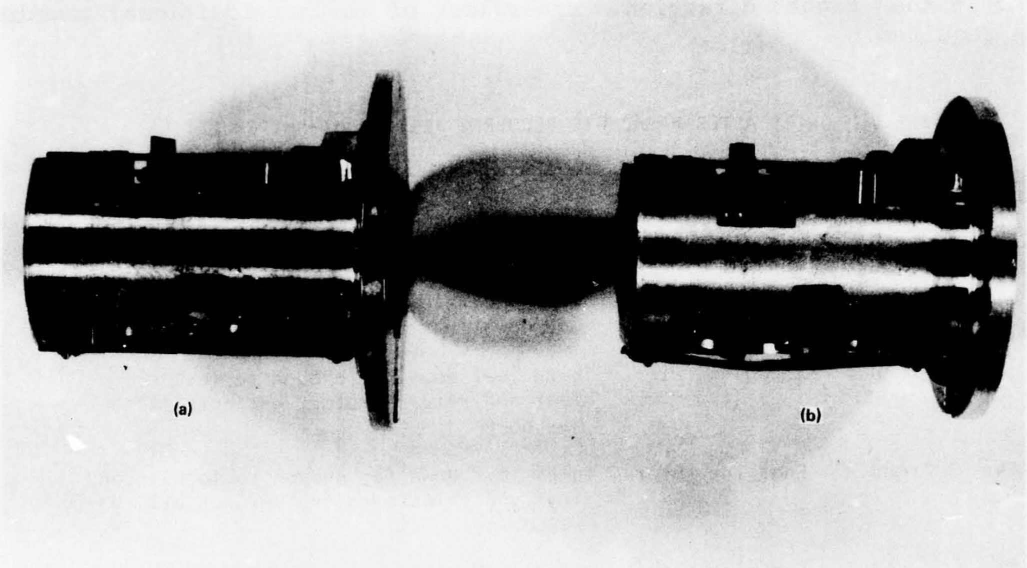


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Figure 32. Arming safety devices after 40-ft drop: (a) vertical, nose up, typical undamaged unit and (b) horizontal, typical damaged unit.

The statistical out-of-line tests consisted of a 20-shot Varicomp with mockup ASD's in which the detonator was 45 deg out of line with the Varicomp lead charge. Boosters were present. An out-of-line mockup consisted of an open-sided housing, a rotor within it, side plates, and a lead charge holder bolted to the bottom of the housing (fig. 35). The Varicomp leads were PETN, PETN being more sensitive than the CH-6 normally used for the lead charge. As desired, none of the leads or boosters were initiated, and none of the lead charge cups were perforated. There was some deformation of the top of some of the lead charge cups, but this is permissible. These tests covered only "early time" effects (possible lead charge initiation), not "late time" effects such as ejection of parts. The mockup parts were in the open and not contained within an enclosing can.

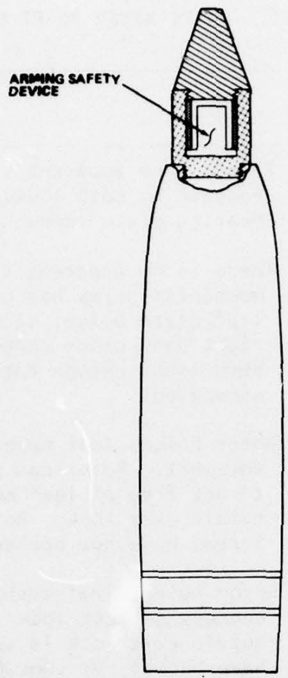


Figure 31. 105-mm vehicle for 40-ft drop test.

The statistical in-line tests consisted of an 18-shot Bruceton at room temperature with mockup hardware, in which the air gap between the detonator and the lead charge was the variable. The in-line mockup hardware consisted of a detonator holder, the actual lead charge, a spacer to provide the air gap between the two, and a collar to position the above parts concentrically (fig. 34). The detonator holder is an axisymmetric part made of the design metal (steel) and having a wall thickness no greater than the minimum rotor thickness around the detonator. A dent block was used in place of the booster. The mean gap over which the detonator would initiate the lead "high order" was 0.5352 in. (1.36 cm). Based on a maximum design gap of 0.062 in. (0.16 cm), these data translate into a reliability of approximately 0.9999999999. A shot producing a dent of 0.020 in. (0.05 cm) or greater in steel was taken as a "go" or "high order." Typical "high order" dents were 0.039 to 0.042 in. (0.099 to 0.11 cm).

The confirmatory in-line tests consisted of 10 shots at low temperature (less than -65 F) with mockup hardware, in which the air gap between the detonator and the lead was the maximum design value of 0.062 in. (0.16 cm). Boosters were present, and dent blocks were used to record the output of the boosters. Each shot resulted in "high order" detonation of the booster. The average dent depth was 0.0886 in. (0.225 cm).

TABLE VI. UNITS AFTER 40-FT DROP TEST

| Unit No. | Orientation | Rotor position | Remarks |
|---|---|---|---|
| 12 | Vertical, nose up | Safe | There is no apparent structural damage. Rotor is engaged by both locks and by escapement. Left bearing plate screw has backed out 1/2 turn. |
| 16 | Vertical, nose down | Safe | There is no apparent structural damage. Lower leaf mechanism screw has backed out 1 or 2 turns. Inner leaf plate bulges slightly near block. Lower right hand clock screw has backed out 1 or 2 turns. Both locks engage rotor. Rotor is engaged by escapement. |
| 23 | 45 deg, nose down | Safe | Rotor bulges leaf mechanism. Escapement bulges somewhat. Rotor can move from side to side enough to get free of leaf mechanism lock, but not of muzzle exit lock. Rotor is engaged to escapement. Screws have not backed out. |
| 5 | Horizontal | Safe | Rotor bulges leaf mechanism. This bulge disengages setback lock from rotor (moves lock away). Muzzle exit lock is engaged, but mounting screws have backed out somewhat so that if lock moved out a little while rotor moved in, rotor could conceivably slip by. Rotor is engaged to escapement. |
| 35 | 45 deg, nose up | Safe | Rotor bulges bearing plate and clock. Rotor is not really locked by setback or muzzle exit lock. It has moved away from them. Rotor is not engaged to escapement. Leaf mechanism bulges somewhat. Rotor is not entirely free to move, but can be vibrated into line. Rotor drive pin is out of rotor. Roll pin that anchors first leaf spring has backed out somewhat. Thus, neither spring is anchored. Leaves can flop down. Muzzle exit lock screws have backed out two or three turns. Other screws have backed out somewhat. |

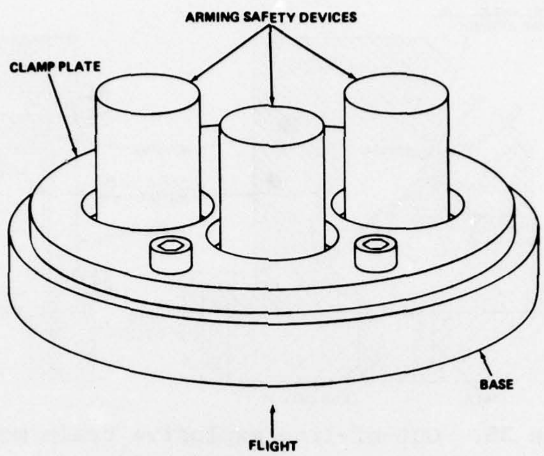


**Figure 33. Fixture for parachute recovery in 8-in. canister.**

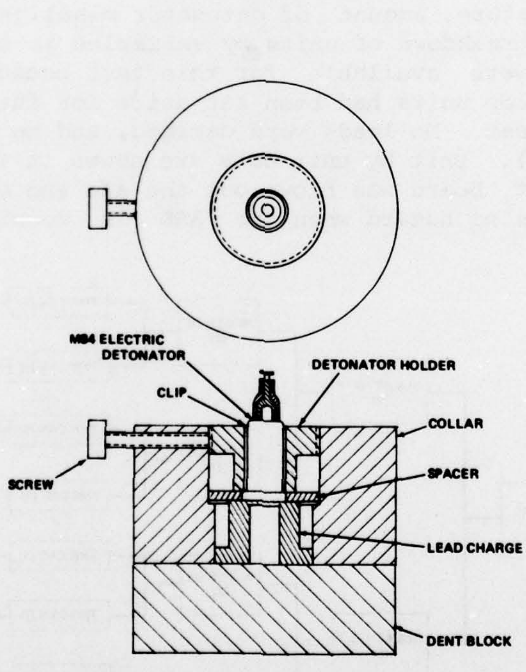


**Figure 34. In-line explosive train mockup.**

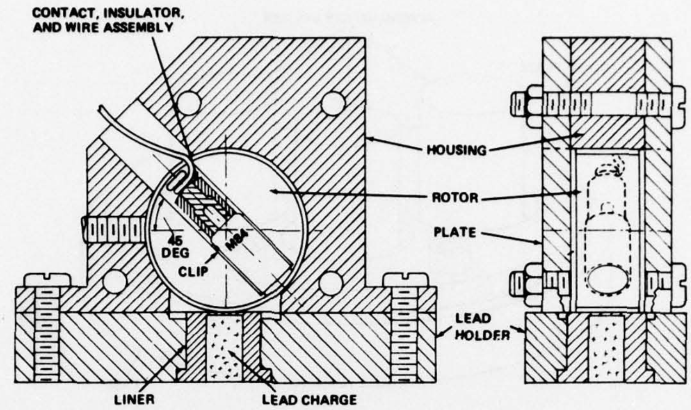


Figure 35. Out-of-line explosive train mockup.

The confirmatory out-of-line tests were conducted with nine units from the recovery firings and the drops. The tests covered three variables: temperature, amount of detonator misalignment, and enclosing can thickness. A breakdown of units by variables is shown in figure 36. Only nine units were available for this test because the questionable 40-ft (12.19-m) drop units had been set aside for future reference. The units passed the test. No leads were damaged, and no enclosing cans were punctured (fig. 37). Unit by unit data are shown in table VII. However, the plastic contact board was blown out the aft end of each unit. Board blowout constitutes no hazard when the ASD is mounted in the warhead.

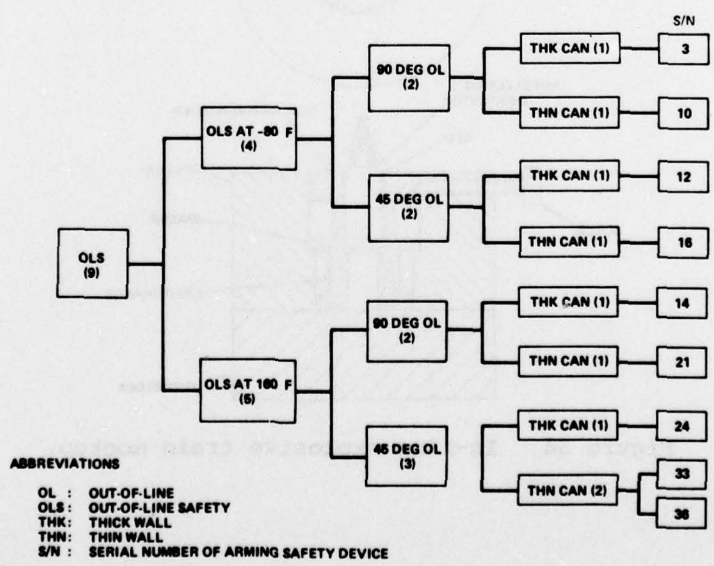


Figure 36. Breakdown of out-of-line safety test by variables.

When out-of-line tests are run in the future, it would be desirable to back up the aft end of the ASD with a simulated mounting plate. This backup would reduce venting of gasses to a level like that in the warhead and would apply a greater pressure to the enclosing can and its crimped joint.

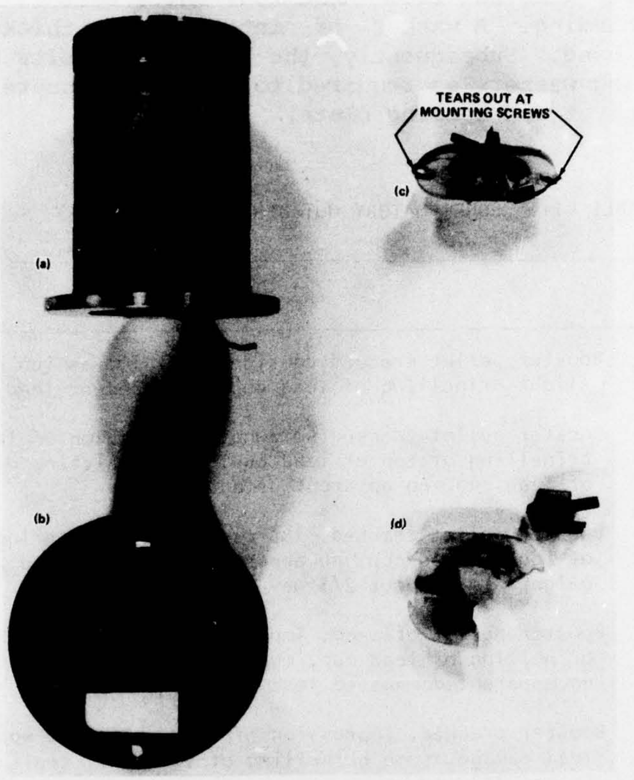


Figure 37. Arming safety devices after confirmatory out-of-line safety test: (a) side view, (b) bottom view, (c) typical contact pad in one piece, and (d) typical contact pad fragments.

Two of the remaining ASD's from the qualification units were prepared for recovery tests in warheads. The ASD's were inert. Each ASD had an empty lead cup and a wax booster pellet, but no detonator. The muzzle exit lock was omitted since there was no means of operating it.

One unit was installed in an inert warhead and launched in an 8-in. parachute recovery vehicle at 8715 g (8000 g desired). There was no apparent damage to the ASD proper, but the rotor was not entirely armed

(5 to 10 deg from the armed position). Post-mortem examination revealed that the front rotor pivot had come out of the pivot hole in the bearing plate because there was inadequate engagement of the pivot and plate. This problem had been recognized earlier on the 25 units and had been remedied by the addition of a spacing washer to the back of the rotor. The washer had been removed from these four units because it was thought to be causing binding. A washer of intermediate thickness probably should have been used. Subsequently, the remaining units on hand were fitted with spacing washers as required to assure adequate engagement of the front rotor pivot and bearing plate.

TABLE VII. CONFIRMATORY OUT-OF-LINE SAFETY TEST

| Temp | Unit No. | Remarks |
|---|---|---|
| -80 F | 16 | Booster pellet cracked considerably, impression of lead, slight brinelling of lead cup, no apparent lead damage |
| | 3 | Booster pellet cracked somewhat, impression of lead, brinelling of top of lead cup, slight pitting of top of lead cup, no apparent damage to lead |
| | 10 | Booster pellet cracked, impression of lead, brinelling of top of lead cup, no apparent damage to lead, slight bulge in can about 2/3 way up |
| | 12 | Booster pellet cracked, impression of lead, slight brinelling of lead cup, much pitting of lead cup, no apparent damage to lead |
| +160 F | 33 | Booster cracked, impression of lead on it, no apparent lead damage, some brinelling of lead cup, small bulge in can 2/3 way up |
| | 24 | Booster cracked, impression of lead on it, brinelling of lead cup, no apparent lead damage |
| | 21 | Booster not cracked, impression of lead on it, more brinelling of lead cup, no apparent lead damage, small bulge in can 2/3 way up |
| | 36 | Booster cracked, impression of lead on it, considerable brinelling of lead cup, no apparent lead damage, small bulge in can 2/3 way up |
| | 14 | Booster not cracked, impression of lead but less than above, brinelling of lead cup, no apparent damage to lead |

*Note: All contact boards blown out.*

The other ASD was installed in a live warhead and launched in a recovery vehicle at approximately 7950 g. Post-mortem examination revealed that there was no damage to the ASD or wax booster pellet and that the ASD had armed. The third leaf was all the way down in the mechanism, and the rotor was locked in line, with the contacts closed.

Two units with modular leaf mechanisms also were prepared for recovery tests in live warheads. (The modular leaf mechanism is explained later in this section.) These ASD's were inert, and the muzzle exit locks were omitted as for the previous two qualification units. Each assembly of an ASD and a live warhead was launched in a recovery vehicle at approximately 7900 g. Post-mortem examination showed that in these ASD's, as in the previous qualification units, there was no damage to the ASD's themselves or to the wax booster pellets and that all ASD's had armed. The third leaf was all the way down in each ASD, and the rotor was in line with the contacts closed. However, the rotor in ASD unit 11 was not locked in line. Consequently, the rotor was approximately 5 to 10 deg from the full in-line position. This constituted out-of-tolerance performance and was analyzed as a failure.

Unit 11 also had not locked in line on the centrifuge in previous laboratory tests. It did lock in line in the arming time test, as all units must. Prior to this recovery test, it was thought that locking in the arming time test was sufficient to assure locking in the field and that locking in the centrifuge test was not necessary. It appears now that locking in the centrifuge test is necessary for locking in the field. In the future, units that are to be delivered for flight tests will be required to lock in the centrifuge test, as well as in the arming time test.

The most likely cause of the failure to lock was that the contact strips were a little too stiff for reliable closing, using the torque available from the spring on the second leaf. Installing the contact board from unit 22 (that did lock) in unit 11 resulted in satisfactory locking of unit 11 on the centrifuge. (Spring torques in the two units were essentially the same based on measurements with a torque watch on the mechanisms themselves.) Future work should address what accounts for the variability in the contact strips and whether thinner strips or greater unsupported lengths are warranted.

As a result of assembly experience with the qualification units and concurrent with the qualification effort, two design modifications were worked out to facilitate assembly: modularization of the leaf mechanism and conversion to a one-piece, premounted strip on the contact board to terminate the piston actuator.

The modularization of the leaf mechanism involved converting three existing spacer posts to staked posts and adding two additional staked

posts (fig. 38). The modular leaf mechanism is positioned when holes in the inner plate fit over pins in the housing. The leaf mechanism seats on the outer plate for the purpose of fastening. This is the present design.

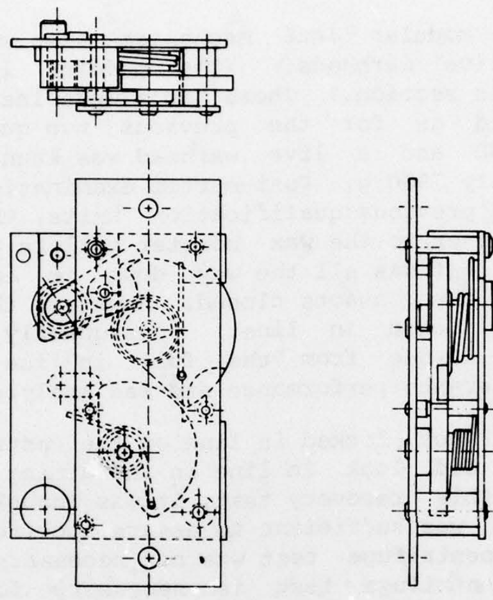

Figure 38. Modular leaf mechanism.

The latest design of the piston actuator contact strip embodies a bent strip, one end of which is mounted to the contact board with crimped fasteners and the other end of which contains a star hole (clash fingers) to press over the center electrode of the piston actuator (fig. 39). The

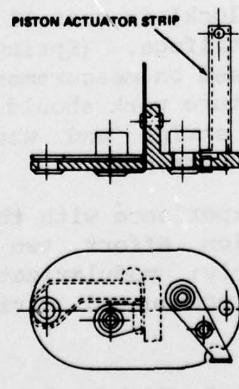


Figure 39. One-piece strip to terminate piston actuator.

star hole technique provides a nearly flush-to-the-housing termination to the piston actuator. This kind of termination is necessary to avoid shorting the actuator to the enclosing can. This is the present design.

## 8. CONCLUSIONS AND RECOMMENDATIONS

The development effort has demonstrated feasibility of the ASD and has resulted in evolutionary improvements in the design. Problems encountered in the test sequence indicate the need for the following additional design refinements:

a. Further improve positioning of the third leaf so that it will hold the second leaf, when armed, in a position to provide adequate clearance for motion of the lock sequencing pin.

b. Reduce contact stiffness to assure that the rotor locks in line in centrifuge tests and in the field.

c. Improve piloting for the lock sequencing pin, and use lighter material for the pin.

d. Reduce rotor mass by changing from steel to aluminum to reduce structural damage in 40-ft (12.19-m) drops.

e. Adjust dimensions and tolerances to eliminate the need for spacing washers on the rotor pivots.

f. Add dry retaining compound to screws.

Some additional testing also is desirable. The efficacy of changing the rotor to aluminum must be verified by 40-ft (12.19-m) drop testing; ASD's with modular leaf mechanisms should be used so that the structural adequacy of the module can be verified at the same time.

The effect of the aluminum rotor on in-line explosive propagation and on out-of-line safety also needs to be evaluated. In-line tests can be done with mockups. The out-of-line tests should be done with real ASD's. These out-of-line tests should be run with the ASD mounted as it would be in the warhead, that is, with the aft end of the ASD backed up with a simulated mounting plate.

Also, a review of the test sequence shows that there are no data on the operability of the muzzle exit lock at temperature extremes. Tests are needed to gather these data.

Upon completion of the recommended design changes and tests, the ASD should be ready for engineering development.

## APPENDIX A.--ANALYTICAL DESIGN OF 1/2-S ESCAPEMENT ASSEMBLY FOR 5-IN. ARMING SAFETY DEVICE

These data help in obtaining a 1/2-s delay with the present torque for the arming safety device used in the 5-in. guided projectile:

Plan: use M532 clock less one stage of gearing

Original main gear travel, 160 deg

Original main gear delay, 9 s

Period at main gear, 9/(160/360) = 20.25 s/revolution

Original torque at main gear, 2.5 in.-oz

Original gear ratio, 157:1

Ratio of stage of gearing to be removed, 4.5:1

With one less gear, new gear ratio, 157/4.5 = 35:1

New period at main gear, $(35/157)\ (35/157)^{1/2}\ (20.25) = 2.13$ s/rev

Travel of main gear for 0.5 s, (0.5/2.13)(360) = 84.5 deg

Since we would like 0.5-s delay in approximately 45 deg rather than 85 deg of travel, the pallet inertia should be increased.

To calculate the new inertia, let

$\tau$ = torque at starwheel,

$\dot{\theta}$ = speed of starwheel,

c = damping constant,

N = number of teeth on starwheel,

$\gamma$ = speed ratio between starwheel and pallet,

P = fraction of engaged motion,

$I_w$ = mass moment of inertia of starwheel and pinion assembly,

$I_p$ = mass moment of inertia of pallet and shaft assembly.

APPENDIX A

Subscript 1 indicates the present value. Subscript 2 indicates the new value.

The following equation relates the starwheel torque and the starwheel speed:

$$\tau = c\dot{\theta}^2 \text{ (footnote 1)},$$

$$c = \frac{2N}{\pi}\gamma^2 \frac{I_p}{I_w} \frac{\left(I_w + P\gamma^2 I_p\right)^2}{I_w + \gamma^2 I_p} \text{ (footnote 2)},$$

$$\dot{\theta} = \left[\frac{\tau}{\frac{2N}{\pi}\gamma^2 \frac{I_p}{I_w} \frac{\left(I_w + P\gamma^2 I_p\right)^2}{I_w + \gamma^2 I_p}}\right]^{1/2} .$$

We wish to obtain $\dot{\theta}_2/\dot{\theta}_1$ in terms of $I_{p2}$ and $I_{p1}$, keeping other parameters constant.

$$\frac{\dot{\theta}_2}{\dot{\theta}_1} = \left\{\frac{\left[\frac{I_{p1}\left(I_w + P\gamma^2 I_{p1}\right)^2}{I_w + \gamma^2 I_{p1}}\right]}{\left[\frac{I_{p2}\left(I_w + P\gamma^2 I_{p2}\right)^2}{I_w + \gamma^2 I_{p2}}\right]}\right\}^{1/2} , \quad \text{(A-1)}$$

$$\frac{\dot{\theta}_2}{\dot{\theta}_1} = \frac{\text{travel of main gear desired}}{\text{travel of main gear now}} = \frac{45 \text{ deg}}{84.5 \text{ deg}} = 0.5325 ,$$

$P \approx 0.5$ (typical),

$\gamma \approx 1$ (typical),

$I_w = 0.0134 \times 10^{-6}$ in.-lbf-s$^2$,

$I_{p1} = 0.0184 \times 10^{-6}$ in.-lbf-s$^2$.

Substituting these values into equation (A-1) and solving the resulting cubic equation for $I_{p2}$ yields $I_{p2} = 0.046 \times 10^{-6}$ in.-lbf-s$^2$.

---

[1] *David L. Overman, Analysis of M125 Booster Mechanism, Harry Diamond Laboratories TR-1550 (June 1971), eq (9).*

[2] *Ibid, eq (24).*

APPENDIX B.--DROP SAFETY OF 5-IN. ARMING SAFETY DEVICE

Drop safety was calculated for the arming safety device in the 5-in. guided projectile. The following equation relates leaf and spring properties to the minimum velocity change (projectile impact velocity) required to arm the leaf:

$$\Delta V_{min} = \sqrt{2g\left(\frac{I}{\frac{Wy}{g}}\right)\left(\theta_t - \theta_i\right)\bar{G}} \quad \text{(footnote 1)},$$

where

$\Delta V_{min}$ = minimum velocity change to arm leaf mechanism,

$g$ = acceleration of gravity,

$I$ = mass moment of inertia of leaf,

$W$ = weight of leaf,

$y$ = radius from pivot to center of gravity of leaf,

$\theta_t$ = total windup of spring on leaf,

$\theta_i$ = initial windup of spring on leaf,

$\bar{G}$ = average spring bias on leaf in nondimensional gravity units (g).

The equation predicts a lower velocity change than is actually required since the equation assumes that the impact deceleration acts on the maximum moment arm of the leaf center of gravity (y) throughout the leaf's motion. The equation also assumes a constant restraint ($\bar{G}$) from the spring on the leaf, treated below as the average value of the actual spring force expressed in nondimensional gravity units (g).

For two leaves, the equation becomes

$$\Delta V_{min} = \sqrt{2g\left(\frac{I_1}{\frac{W_1 y_1}{g}}\right)\left(\theta_{1t} - \theta_{1i}\right)\bar{G}_1} + \sqrt{2g\left(\frac{I_2}{\frac{W_2 y_2}{g}}\right)\left(\theta_{2t} - \theta_{2i}\right)\bar{G}_2} .$$

---

[1] *William E. Ryan, Analysis and Design--Rotary Setback Leaf S&A Mechanism, Harry Diamond Laboratories TR-1190 (11 February 1964), eq (35) (modified for a single leaf).*

APPENDIX B

Subscript 1 indicates leaf No. 1, and subscript 2 indicates leaf No. 2.

These values apply to the following calculations:

$g = 386$ in./s$^2$,

$I_1 = 3.46 \times 10^{-7}$ in.-lbf-s$^2$,

$W_1 = 0.00340$ lbf,

$y_1 = 0.0921$ in.

$\theta_{1i} = 1.571$ radians,

$\theta_{1t} = 2.443$ radians,

$\lambda_1 = 0.756$ in.-oz/radian (rate of spring on leaf),

$I_2 = 5.32 \times 10^{-7}$ in.-lbf-s$^2$,

$W_2 = 0.00331$ lbf,

$y_2 = 0.135$ in. ,

$\theta_{2i} = 0$ radian,

$\theta_{2t} = 1.96$ radians,

$\lambda_2 = 2.11$ in.-oz/radian,

$H_{min}$ = minimum safe drop height.

$$\frac{I_1}{\dfrac{W_1 y_1}{g}} = \frac{(3.46)(10^{-7})}{\left(\dfrac{0.00340}{386}\right)(0.0921)} = 0.426 \text{ in.},$$

$$\theta_{1t} - \theta_{1i} = 2.443 - 1.571 = 0.872 \text{ rad},$$

$$\bar{G}_1 = \frac{\dfrac{\lambda_1\left(\theta_{1i} + \theta_{1t}\right)}{2}}{W_1 y_1} = \frac{\dfrac{(0.756)(1.57 + 2.44)}{2}}{[(0.00340)(16)](0.0921)} = 302 \text{ g},$$

$$\frac{I_2}{\frac{W_2 y_2}{g}} = \frac{(5.32)\ (10^{-7})}{\left(\frac{0.00331}{386}\right)(0.135)} = 0.460 \text{ in.},$$

$$\theta_{2t} - \theta_{2i} = 1.96 - 0 = 1.96 \text{ rad},$$

$$\bar{G}_2 = \frac{\frac{\lambda_2\left(\theta_{2i} + \theta_{2t}\right)}{2}}{W_2 y_2} = \frac{\frac{(2.11)(0 + 1.96)}{2}}{[(0.00331)(16)](0.135)} = 289 \text{ g},$$

$$\Delta V_{min} = \sqrt{(2)(386)(0.426)(0.872)(302)} + \sqrt{(2)(386)(0.460)(1.96)(289)}$$

$$= 294 + 448$$

$$= 742 \text{ in./s } (61.8 \text{ ft/s}),$$

$$H_{min} = \frac{\left(\Delta V_{min}\right)^2}{2g} = \frac{(61.8)^2}{(2)\left(\frac{386}{12}\right)} = 59 \text{ ft.}$$

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